Amendments to the Specification:

In the following discussion, paragraph number references are to those paragraph numbers contained in the original specification filed on July 24, 2003.

Please add the following new paragraphs after paragraph [0056]:

[0056.1] FIG. 21 is a graph of the induced voltage pulses (v_{gen}) within the coil of the magnet-coil generator as the tire rotates into and out of the road contact region.

[0056.2] FIG. 22 is a graph of the expected magnetic field (B_x) vs. distance from pole (x) vs. magnet length (L) and radius (r) where B_r is normalized to one.

[0056.3] FIG. 23 is a graph of a half-sine model of the induced voltage (v_{gen}) showing its peak value, period, a voltage threshold and the time the voltage is above the threshold.

[0056.4] FIG. 24 is a graph showing v_{gen} (solid) and v_c (dotted) for T = 1.5 msec, v_{genMax} = 10 volts, ω_{RC} = 4000 rad/sec for an energy-optimal capacitor value and for a non-optimal value.

[0056.5] FIG. 25 is a graphical plot of E_{cMax} (joules), $\omega_{gen}R_{source}C$ and $\omega_{gen}t_{max}$ for (A) T = 6 msec, v_{genMax} = 2 volts, R_{source} = 1 ohm; (B) T = 3 msec, v_{genMax} = 4 volts, R_{source} = 1 ohm; (C) T = 1.5 msec, v_{genMax} = 8 volts, R_{source} = 1 ohm; (D) T = 0.75 msec, v_{genMax} = 16 volts, R_{source} = 1 ohm.

[0056.6] FIG. 26 is a graph showing experimental verification of the optimal capacitor calculation for a 300-Hz and a 600-Hz sine.

[0056.7] FIG. 27 is a graphical plot of the magnet-coil generator circuit voltages vs. time with v_{gen} the internal coil voltage, v_{coil} the external measurable coil voltage, and v_c the capture capacitor voltage after full-wave rectification of v_{coil} and during discharge; also shown is the relationship of the signals to the off- and on-road contact status of the tire as well as threshold settings used to measure the v_{coil} pulse widths and periodicity.

[0056.8] FIG. 28 is a graph of the centrifugal acceleration at the tread and as a function of vehicle speed for a typical 1-foot radius passenger tire.

[0056.9] FIG. 29 is a graph of the voltage vs. time generated by a demonstration radial magnet-coil inner wall deflection generator.

[0056.10] FIG. 30 is a graphical plot of the piezo-electric generator circuit voltages vs. time: the open circuit unloaded piezo voltage v_{piezo}, the actual piezo voltage with loading by the capture capacitor, and the v_c the capture capacitor voltage after peak capture of the actual v_{piezo} and during discharge; also shown is the relationship of the signals to the off- and on-road contact status of the tire as well as a threshold setting used to measure the v_{piezo} pulse widths and periodicity.

Please replace paragraph [0063] with the following amended paragraph:

[0063] The electricity generated by generator 30 consists of positive and negative pulses, as the inner wall deflects outward and returns inward, and is captured on a capacitor and converted to regulated power by, for example, a conventional solid state switching regulator 54. A basic schematic is presented generally as numeral 50 in FIG. 5, an equivalent circuit in FIG. 6, and the induced voltage pulses are illustrated in ~~Graph 1~~ FIG. 21. A diode is used as a half-wave rectifier 52 to select the positive going pulse and form a peak voltage capture circuit in conjunction with the capacitor 58. Alternately, a full-wave rectifier captures both the positive and negative pulses.

Please delete Graph 1 from paragraph [0063].

Please replace paragraph [0068] with the following amended paragraph:

[0068] Although the NdFeB magnets are inexpensive as far as Rare Earth magnets go, a smaller magnet is still less expensive than a larger one but a long magnet is needed to give room to form a coil of around half its length. For magnetic materials with straight line normal demagnetization curves, such as Rare Earths and Ceramics, the magnetic field generated by a cylindrical magnet with poles on its ends at a distance x from a pole along its axis is generally given by

$$B_x = \frac{B_R}{2}\left(\frac{L_{magnet} + x}{\sqrt{r_{magnet}^2 + (L_{magnet} + x)^2}} - \frac{x}{\sqrt{r_{magnet}^2 + x^2}}\right)$$

where L_{magnet} is its length and r_{magnet} is its radius. This field as a function of x and of L_{magnet} is shown in ~~Graph 2~~ FIG. 22 and illustrates the relative insensitivity of B to the

length of the magnet. From these graphs we see that a magnet with a length greater or equal to its diameter will maintain over 90% of its maximum field of 0.5 B_r. This means short and therefore less expensive magnets can be used.

Please delete Graph 2 from paragraph [0068].

Please replace paragraph [0072] with the following amended paragraph:

[0072] The voltage generated within the coil is modeled as a half sine wave having a peak voltage v_{genMax} and a pulse width of T seconds, as shown in ~~Graph 3~~ <u>FIG. 23</u>. This representation accounts for the Fourier fundamental first harmonic of any actual signal and provides a continuously differentiable formulation for subsequent analysis. The sinusoidal signal has a frequency in radians/sec of

$$\omega_{gen} = \frac{\pi}{T}$$

and the LaPlace transform of the sine function is

$$V_{gen}(s) = \frac{v_{genMax}\omega_{gen}}{s^2 + \omega_{gen}^2}$$

The LaPlace transform of the voltage across the capacitor is calculated as

$$\begin{aligned} V_c(s) &= \frac{\omega_{RC}}{s + \omega_{RC}} V_{gen}(s) \\ &= \omega_{RC} v_{genMax} \omega_{gen} \frac{1}{s + \omega_{RC}} \frac{1}{s^2 + \omega_{gen}^2} \end{aligned}$$

which is written using partial fractions as

$$V_c(s) = \frac{\omega_{RC} v_{genMax} \omega_{gen}}{\omega_{RC}^2 + \omega_{gen}^2} \left(\frac{1}{s + \omega_{RC}} + \frac{\omega_{RC} - s}{s^2 + \omega_{gen}^2} \right)$$

The inverse LaPlace transform (ignoring forward voltage drops across the rectifier) is then

$$v_c(t) = \frac{\omega_{RC} v_{genMax}}{\omega_{RC}^2 + \omega_{gen}^2} \left(\omega_{gen} e^{-\omega_{RC} t} - \omega_{gen} \cos \omega_{gen} t + \omega_{RC} \sin \omega_{gen} t \right)$$

which represents the voltage across the capacitor up to the instant when it is equal to $v_{gen}(t)$ after which it does not change. Illustrations of the results of this equation are presented in ~~Graph 4~~ <u>FIG. 24</u>.

Please delete Graph 3 and Graph 4 from paragraph [0072].

Please replace paragraph [0073] with the following amended paragraph:

[0073] The rectified voltage captured on the capacitor has a positive derivative up to the instant it crosses $v_{gen}(t)$ where the derivative goes to zero. As such, the voltage is the maximum value of v_c over the pulse width and is defined as the value of v_c at the time t_{max} when $\dot{v}_c = 0$

$$\dot{v}_c(t_{\max}) = \frac{\omega_{RC} \omega_{gen} v_{genMax}}{\omega_{RC}^2 + \omega_{gen}^2} \left(-\omega_{RC} e^{-\omega_{RC} t_{\max}} + \omega_{gen} \sin \omega_{gen} t_{\max} + \omega_{RC} \cos \omega_{gen} t_{\max} \right) \equiv 0$$

or, alternatively and equivalently, when $v_c = v_{gen}$

$$v_{genMax} \sin \omega_{gen} t_{\max} = \frac{\omega_{RC} v_{genMax}}{\omega_{RC}^2 + \omega_{gen}^2} \left(\omega_{gen} e^{-\omega_{RC} t} - \omega_{gen} \cos \omega_{gen} t + \omega_{RC} \sin \omega_{gen} t \right)$$

Both conditions occur at a time t_{max} defined by

$$f(t_{\max}) = -\omega_{RC} e^{-\omega_{RC} t_{\max}} + \omega_{gen} \sin \omega_{gen} t_{\max} + \omega_{RC} \cos \omega_{gen} t_{\max} \equiv 0$$

This transcendental equation cannot be solved in closed form, but is resolved numerically using a Newton-Raphson iterative algorithm

$$\begin{aligned} t_{\max,0} &= 0.8T \\ f(t_{\max,i}) &= -\omega_{RC} e^{-\omega_{RC} t_{\max,i}} + \omega_{gen} \sin \omega_{gen} t_{\max,i} + \omega_{RC} \cos \omega_{gen} t_{\max,i} \\ \left.\frac{df(t)}{dt}\right|_{t=t_{\max,i}} &= \omega_{RC}^2 e^{-\omega_{RC} t_{\max,i}} + \omega_{gen}^2 \cos \omega_{gen} t_{\max,i} - \omega_{RC} \omega_{gen} \cos \omega_{gen} t_{\max,i} \\ t_{\max,i+1} &= t_{\max,i} - \frac{f(t_{\max,i})}{\left.\frac{df(t)}{dt}\right|_{t=t_{\max,i}}} \end{aligned}$$

The algorithm iteratively improves the $t_{max,0}$ initial estimate of t_{max} and is stopped after a few iterations when no significant changes are noted. Applying this algorithm to the example of ~~Graph 4~~ FIG. 24, $t_{max,0}$ converges to a value of 1.227 msec with three iterations.

Please replace paragraph [0075] with the following amended paragraph:

[0075] To illustrate, begin with a somewhat arbitrary set of parameters representing the signals at 10 mph on a 12" radius tire with a 4" contact patch length and an R_{source} = 1 ohm

$v_{genMax@10mph}$ = 2V

T_{10mph} = 6 msec

and scale up to 20, 40, and 80 mph by scaling the voltage upward and the pulse width downward with speed

$v_{genMax@20mph}$ = 4V

T_{20mph} = 3 msec

$v_{genMax@40mph}$ = 8V

T_{40mph} = 1.5 msec

$v_{genMax@80mph}$ = 16V

T_{80mph} = 0.75 msec

The results of applying the optimization algorithm are presented in Graph 5. The optimal capacitor values that maximize the captured energy range from 3200μF at 10 mph to 450μF at 80 mph. Also shown on ~~Graph 5~~ FIG. 25 are two factors, $\omega_{gen}R_{source}C$ and $\omega_{gen}t_{max}$, which are further considered below.

Please delete Graph 5 from paragraph [0075].

Please replace paragraph [0076] with the following amended paragraph:

[0076] *Determining the Theoretical Conditions for Optimality*: At the peak energy capture points in all these figures

$$\omega_{gen}R_{source}C_{optimal} \approx 1.7$$
$$\omega_{gen}t_{max} \approx 2.5$$

the conditions for optimality are found as those that make the partial derivatives of E_c with respect to t and C equal zero. After some elementary calculus and algebra, the conditions are

- for the partial derivative with respect to t to be zero at t_{max} and $C_{optimal}$

$$\omega_{gen}R_{source}C_{optimal}\sin\omega_{gen}t_{\max} + \cos\omega_{gen}t_{\max} - e^{-t_{\max}/R_{source}C_{optimal}} = 0$$

- for the partial derivative with respect to C to be zero at t_{max} and $C_{optimal}$

$$e^{-t_{\max}/R_{source}C_{optimal}}\left\{[3-(\omega_{gen}R_{source}C_{optimal})^2]\omega_{gen}R_{source}C_{optimal}+2[1+(\omega_{gen}R_{source}C_{optimal})^2]\omega_{gen}t_{\max}\right\}-$$
$$[3-(\omega_{gen}R_{source}C_{optimal})^2]\omega_{gen}R_{source}C_{optimal}\cos\omega_{gen}t_{\max}+[1-3(\omega_{gen}R_{source}C_{optimal})^2]\sin\omega_{gen}t_{\max}=0$$

These equations are re-written as

$$\alpha\sin\beta+\cos\beta-e^{-\beta/\alpha}=0$$
$$[(3-\alpha^2)\alpha+2(1+\alpha^2)\beta]e^{-\beta/\alpha}-(3-\alpha^2)\alpha\cos\beta+(1-3\alpha^2)\sin\beta=0$$

where the α and β constants are related to the model as

$$\alpha=\omega_{gen}R_{source}C_{optimal}$$
$$\beta=\omega_{gen}t_{\max}$$

It is apparent that these are two purely parametric simultaneous equations depend only on the constant parameters α and β that are not functions of time. Solving the equations numerically

$$\alpha=\omega_{gen}R_{source}C_{optimal}\equiv 1.7105$$
$$\beta=\omega_{gen}t_{\max}\equiv 2.4949$$

Importantly, these are the same values detected in the numerical experiments shown on ~~Graph 5~~ FIG. 25**.**

Please replace paragraph [0082] with the following amended paragraph:

[0082] *Laboratory Verification of Optimality*: The optimality conditions are experimentally verifiable. A single 22V peak-to-peak sinusoidal cycle (11 volt v_{genMax}) was used to drive a 1000 ohm 1% resistor in series with a 1N4006 diode to which various capacitors were attached. The in-circuit capacitance was measured using a WaveTek DM27SXT meter, a single sinusoidal cycle was applied, the peak-captured voltage was measured, and the captured energy calculated. Two examples are shown in ~~Graph 6~~ FIG. 26, a 300-Hz sine and a 600-Hz sine.

Please delete Graph 6 from paragraph [0082].

Please replace paragraph [0083] with the following amended paragraph:

[0083] For the 300-Hz sine example, T = 1.67 msec, v_{gen} = 10.4 volts (after subtracting the 0.6V forward drop of the diode), and the expected optimal capacitor is

$$C_{optimal} = \frac{1.7105}{\omega_{gen} R_{source}} = \frac{1.7105}{2\pi f_{gen} R_{source}}$$
$$= \frac{1.7105}{2\pi(300)(1000)} = 0.91\mu F$$

From ~~Graph 6~~ FIG. 26, the peak occurs between 0.7-1.0 μF; at 0.8μF the captured peak, v_{cMax}, is 6.24V (59% of v_{genMax}); t_{max} = 1.34 msec (80% of T); and the captured energy is 15.2μJ as compared to the anticipated energy

$$E_{cMax} = 0.363 \frac{C_{optimal}}{2} v_{genMax}^2$$
$$= 0.181 C_{optimal} v_{genMax}^2$$
$$= 0.181(0.8x10^{-6})(10.4)^2$$
$$= 15.6\mu Joules$$

All calculated values are in agreement with the optimal conditions.

Please replace paragraph [0084] with the following amended paragraph:

[0084] For the 600-Hz sine example, T = 0.833 msec, v_{gen} = 10.6 volts (after subtracting the 0.6V forward drop of the diode) the expected optimal capacitor is

$$C_{optimal} = \frac{1.7105}{2\pi(600)(1000)} = 0.45\mu F$$

From the graph in FIG. 26, the peak occurs between 0.3-0.5 µF; at 0.4µF the captured peak, v_{cMax}, is, again, 6.24V (59% of v_{genMax}); t_{max} = 0.676 msec (81% of T); and the captured energy is 7.7µJ as compared to the anticipated energy

$$\begin{aligned} E_{cMax} &= 0.181 C_{optimal} v_{genMax}^2 \\ &= 0.181(0.4x10^{-6})(10.4)^2 \\ &= 7.8 \mu Joules \end{aligned}$$

Again, all calculated values are in agreement with the anticipated optimal conditions.

Please replace paragraph [0086] with the following amended paragraph:

[0086] One method of determining pulse width from an unloaded positive (or negative) pulse is by setting a threshold level, $v_{threshold}$, and measuring the time, τ, during which the pulse is larger (or less) than the threshold, as shown in ~~Graph 3~~ FIG. 23. The peak voltage, v_{genMax}, is measured during this timing process and the pulse width determined as

$$v_{threshold} = v_{genMax} \cos\left(\frac{\pi}{T}\frac{\tau}{2}\right)$$

$$\therefore T = \frac{\pi}{2\cos^{-1}(v_{threshold} / v_{genMax})}\tau$$

Other methods of determining pulse width are described in the following circuitry discussion.

Please replace paragraph [0088] with the following amended paragraph:

[0088] The early positive going pulse is used to capture energy and the negative pulse is used to determine pulse width. It may seem wasteful not to use the negative pulse for energy, but this second pulse is useful only during its portion having a voltage greater than that already captured on the capacitor by the first pulse (the upper 40% if the optimal capacitor is being used) and does not contribute nearly as much energy as the first pulse. ~~Graph 7~~ FIG. 27 illustrates the pertinent circuit voltages assuming a full-wave rectifier is used and that the energy capture capacitor is fully discharged by the switching regulator between cycles.

Please delete Graph 7 from paragraph [0088].

Please replace paragraph [0091] with the following amended paragraph:

[0091] Returning to the examples of ~~Graph 5~~ FIG. 25, the capacitance range can be handled with three capacitors of values 500μF, 1000μF and 2000μF that, in combination, provide seven capacitance values ranging from 500μF to 3500μF, with 500μF steps in addition to no capacitance loading.

Please replace paragraph [0092] with the following amended paragraph:

[0092] Other alternate methods can be used to select the optimal capacitor. As suggested by ~~Graph 5~~ FIG. 25, the capacitor value can be dithered and the resulting acquired energy calculated to track the optimal capacitor value. For example, consider that when using a nominal capacitance C_0 the acquired voltage on a capacitor (as determined for example by A/D conversion) is measured as v_{c0} and the energy captured is calculated as $E_0 = C_0 v_{c0}^2/2$. The capacitor value is subsequently dithered (perturbed) by using a larger value, C_+, v_{c+} measured and $E_+ = C_+ v_{c+}^2/2$ calculated. If the energy is greater using C_+ then switch to this capacitor value. Otherwise use a smaller capacitor, C_-, and see if it provides more energy. A dither controller is shown in FIG. 8 and is very similar to that of FIG. 7. The rising edge of the pass transistor 78a signal indicates the negative v_{coil} pulse has arrived and that the positive pulse has ended. That occurrence indicates the voltage on the capacitor bank 88a, 88b, and 88c is to be measured and used to calculate the energy captured.

Please replace paragraph [0096] with the following amended paragraph:

[0096] The horizontal generator 90 is affected by centrifugal acceleration and the magnetic susceptibility of the tire steel belts 112. The rotating tire acts as a centrifuge and generates a large acceleration radially outward from the wheel rim center

$$\begin{aligned} a_{centrifugal} &= r_{tire}\,\omega_{tireRotation}^2 \\ &= r_{tire}\left(\frac{s_{vehicle}}{2\pi r_{tire}}\right)^2 \\ &= \frac{s_{vehicle}^{\;2}}{4\pi^2 r_{tire}} \end{aligned}$$

where $s_{vehicle}$ is the speed of the vehicle are r_{tire} the tire radius. This acceleration is illustrated in ~~Graph 8~~ FIG. 28 for a typical 1 ft radius passenger tire, and places a large load on the fasteners 100 and 102 and on the guide tube 94 holding the magnet (e.g. 244 g's at 60 mph).

Please delete Graph 8 from paragraph [0096].

Please replace paragraph [0102] with the following amended paragraph:

[0102] A typical result taken from the demonstrator while the vehicle is moving at 8 mph is shown in ~~Graph 9~~ FIG. 29. It consists of a positive leading edge pulse caused by the inner wall deflection pulling the coil upward, and a negative trailing edge pulse caused by a 4g centrifugal force.

The half-sinusoidal positive leading edge pulse has a v_{genMax} = 300 mv; T = 30 msec; and is repeated every 540 msec. For such a signal, the optimal energy capture circuitry is

R_{source} = 1.1 ohm

$C_{optimal}$ = 14,850 μF

v_{cMax} = 181 mv

E_c = 243 μJ

P_c = 0.45 mW

Projecting from these values, if the vehicle were traveling at 40 mph, then v_{genMax} = 1500 mv; T = 6 msec; the pulse is repeated every 108 msec; the centrifugal force is 106g; and

R_{source} = 1.1 ohm

$C_{optimal}$ = 2970 μF

v_{cMax} = 0.905 v

E_c = 1215 μJ

P_c = 11.2 mW

If the vehicle were traveling at 60 mph, then v_{genMax} = 2.25 v; T = 4 msec; the pulse is repeated every 72 msec; the centrifugal force is 239g; and

R_{source} = 1.1 ohm

$C_{optimal}$ = 2178 μF

v_{cMax} = 1.98 v

E_c = 1822 μJ

P_c = 25.3 mW

Please delete Graph 9 from paragraph [0102].

Please replace paragraph [0111] with the following amended paragraph:

[0111] If the piezo circuitry has significant source resistance (e.g. the rectifier 52), the energy captured on the capacitor is reduced but, using the same logic as for the magnet-coil generator, an optimal capture capacitor can be calculated. If in FIG. 15 the normally large piezo internal resistance 172 R_{piezo} is ignored, and the rectifier 52 replaced by a source resistance R_{source} representing all resistance from the piezo 142 to the capture capacitor 58, the coupled differential equations representing v_{piezo} and v_c are

$$\dot{v}_{piezo}(t) = \frac{v_c - v_{piezo}}{R_{source} C_{piezo}}$$

$$\dot{v}_c(t) = \frac{v_{piezo} - v_c}{R_{source} C}$$

having initial conditions

$$v_{piezo}(0) = \frac{Q_{piezo}}{C_{piezo}}$$

$$v_c(0) = 0$$

Applying elementary calculus, these coupled equations are solved as

$$v_{piezo}(t) = \frac{Q_{piezo}}{C_{piezo} + C}\left(1 + \frac{C}{C_{piezo}} e^{-\frac{C_{piezo}+C}{R_{source}C_{piezo}C}t}\right)$$

$$v_c(t) = \frac{Q_{piezo}}{C_{piezo} + C}\left(1 - e^{-\frac{C_{piezo}+C}{R_{source}C_{piezo}C}t}\right)$$

as illustrated in ~~Graph 10~~ FIG. 30.

Please delete Graph 10 from paragraph [0111].

Please replace paragraph [0124] with the following amended paragraph:

[0124] As illustrated in ~~Graph 7 and Graph 10~~ FIG. 27 and FIG. 30, the time duration of the contact length (contactTime) is measured by timing the magnet-coil generator v_{coil} pulses or the duration of the piezo-electric generator v_{piezo} pulse. The same signals are used to measure the rotation period of the tire (rotationPeriod). The length of the contact region 20 is given by

$$\begin{aligned} contactLength &= 2tireRadius \times sin\left\langle \frac{\pi}{rotationPeriod}\left(contactTime + \frac{contactBias \times rotationPeriod}{2\pi \times tireRadius}\right)\right\rangle \\ &= 2tireRadius \times sin\left\langle \frac{\pi \times contactTime}{rotationPeriod} + \frac{contactBias}{2tireRadius}\right\rangle \\ &\approx 2\pi \times tireRadius\left(\frac{contactTime}{rotationPeriod}\right) + contactBias \end{aligned}$$

where contactBias is the effective footprint of the sensor along the circumference of the tire. Contact length is used to determine the tire rolling radius, volume, deflation, deflection angle, and (with tire pressure) the load on the tire, and (with tire temperature) the molar gas content in the tire, and other tire parameters. The loads on the tires are used to determine the mass of the vehicle, the distribution of mass, the location of the center-of-mass, and other vehicle parameters.